Appendix A. Description of Hydrodynamic Analytical Tools and Summary of Modeling Results

This appendix presents descriptions of analytical tools (A.1), and a summary of modeling results (A.2). The following tables and figures are presented:

Figure A-1. Schematic of DSM2 Modules

Table A-1. Key Observations from Modeling Results

Figure A-1a. Simulated Delta operational controls in Option 1 and Option 2

Figure A-2b. Simulated Delta operational controls in Option 3 and Option 4

Figure A-3. Sacramento River at Rio Vista monthly average flow for below normal years

Figure A-4. Delta outflow monthly average flow for below normal years

Figure A-5. Monthly average X2 position for below normal years

Figure A-6. QWEST monthly average flow for below normal years

Figure A-7. Combined Old and Middle River monthly average flow for below normal years

Figure A-8. CVP/SWP annual export reliability

Figure A-9. CVP north of Delta end of September storage (Shasta plus Folsom) exceedance probability

Figure A-10. SWP north of Delta end of September storage (Oroville) exceedance probability

Figure A-11. Average export water quality, 1975-1991

Figure A-12. In Delta average water quality, 1975-1991

APPENDIX A. DESCRIPTION OF HYDRODYNAMIC ANALYTICAL TOOLS AND SUMMARY OF MODELING RESULTS

A.1 DESCRIPTION OF ANALYTICAL TOOLS

A.1.1 CALSIM II PLANNING MODEL

The California Department of Water Resources (DWR)/U. S. Bureau of Reclamation (USBR) CALSIM II planning model was used to simulate the operation of the CVP and SWP over a range of hydrologic conditions. CALSIM is a generalized reservoir-river basin simulation model that allows for specification and achievement of user-specified allocation targets, or goals (Draper et al., 2002). The current application to the Central Valley system is called CALSIM II and represents the best available planning model for the SWP and CVP system operations.

The CALSIM simulation model uses single time-step optimization techniques to route water through a network of storage nodes and flow arcs based on a series of user-specified relative priorities for water allocation and storage. Physical capacities and specific regulatory and contractual requirements are input as linear constraints on system operation using the water resources simulation language (WRESL). The process of routing water through the channels and storing water in reservoirs is performed by a mixed-integer linear programming (MIP) solver. For each time step, the solver maximizes the objective function to determine a solution that delivers or stores water according to the specified priorities and satisfies all system constraints. The sequence of solved MIP problems represents the simulation of the system over the period of analysis.

CALSIM II includes a new hydrology developed jointly by DWR and USBR. Water diversion requirements (demands), stream accretions and depletions, rim basin inflows, irrigation efficiency, return flows, non-recoverable losses, and groundwater operation are components that make up the hydrology used in CALSIM II. Sacramento Valley and tributary rim basin hydrologies are developed using a process designed to adjust the historical sequence of monthly stream flows to represent a sequence of flows at a future level of development. Adjustments to historic water supplies are determined by imposing future level land use on historical meteorological and hydrologic conditions. The resulting hydrology represents the water supply available from Central Valley streams to the CVP and SWP at a future level of development.

CALSIM II also uses an Artificial Neural Network (ANN), developed by DWR, to simulate flow-salinity relationships so that salinity requirements at critical locations in the Delta can be maintained while implementing new operations. The ANN model approximates DSM2 model-generated salinity at the following key locations for the purpose of modeling Delta water quality standards: Sacramento River at Emmaton, San Joaquin River at Jersey Point, Sacramento River at Collinsville, and Old River at Rock Slough. The ANN model incorporates antecedent Delta conditions as well as "carriage water" type influences.

CALSIM II uses logic for determining deliveries to north-of-Delta and south-of-Delta CVP and SWP contractors. The delivery logic uses runoff forecast information, which incorporates uncertainty and standardized rule curves. The rule curves relate storage levels and forecasted water supplies to project delivery capability for the upcoming year. The delivery capability is then translated into SWP and CVP contractor allocations which are satisfied through coordinated reservoir-export operations.

Additional information on the CALSIM II model can be found on the DWR Modeling Support Branch website at http://modeling.water.ca.gov/.

A.1.2 DELTA SIMULATION MODEL (DSM2)

DSM2 is a one-dimensional hydrodynamic and water quality simulation model used to simulate hydrodynamics, water quality, and particle tracking in the Sacramento-San Joaquin Delta (DWR, 2002). DSM2 represents the best available planning model for Delta tidal hydraulic and salinity modeling. It is appropriate for describing the existing conditions in the Delta, as well as performing simulations for the assessment of incremental environmental impacts caused by facilities and operations. The DSM2 model has three separate components: HYDRO, QUAL, and PTM. The relationship between HYDRO, QUAL and PTM is shown in A-1.

The HYDRO module is a one-dimensional, implicit, unsteady, open channel flow model that DWR developed from FOURPT, a four-point finite difference model originally developed by the USGS in Reston, Virginia. DWR adapted the model to the Delta by revising the input-output system, including open water elements, and incorporating water project facilities, such as gates, barriers, and the Clifton Court Forebay. HYDRO simulates velocities and water surface elevations. HYDRO provides the flow input for QUAL and PTM.

The QUAL module is a one-dimensional water quality transport model that DWR adapted from the Branched Lagrangian Transport Model originally developed by the USGS in Reston, Virginia. DWR added many enhancements to the QUAL module, such as open water areas and gates. A Lagrangian feature in the formulation eliminates the numerical dispersion that is inherently in other segmented formulations, although the tidal dispersion coefficients must still be specified. QUAL simulates fate and transport of conservative and non-conservative water quality constituents given a flow field simulated by HYDRO.

PTM simulates pseudo 3-D transport of neutrally buoyant particles based on the flow field simulated by HYDRO. The PTM module simulates the transport and fate of individual particles traveling throughout the Delta. The model uses velocity, flow, and stage output from the HYDRO module to monitor the location of each individual particle using assumed vertical and lateral velocity profiles and specified random movement to simulate mixing. PTM has multiple applications ranging from visualization of flow patterns to simulation of discrete organisms such as fish eggs and larvae.

Additional information on DSM2 can be found on the DWR Modeling Support Branch website at http://modeling.water.ca.gov/.

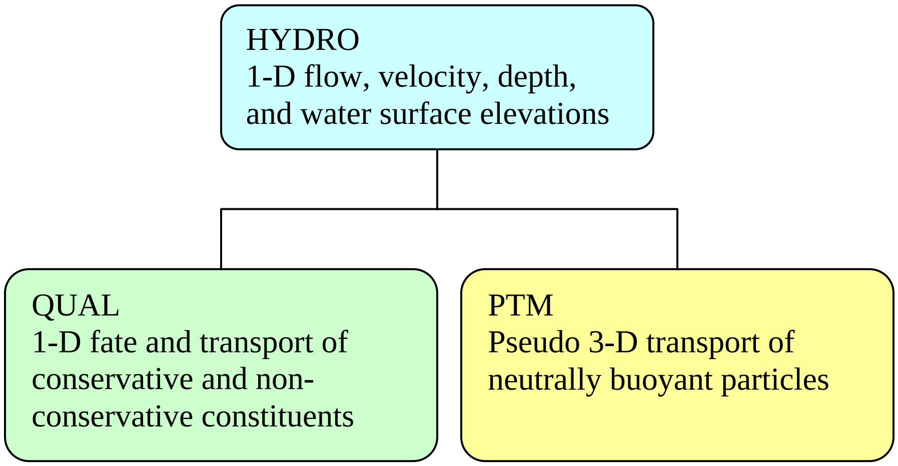


Figure A-1. Schematic of DSM2 Modules

A.1.3 MODELING LIMITATIONS

While the CALSIM II and DSM2 models are the best available planning tools for integrated Central Valley hydrology, CVP/SWP systems operation, and Delta hydrodynamic and water quality analyses, there are several limitations with the models and analytical process that should be highlighted. As was discussed previously, the modeling performed for this evaluation report should be considered "screening-level", consistent with the objectives and timeframe for this report. More refined modeling analyses should be performed to evaluate individual options further.

One of the main limitations of the CALSIM II model is the time step of simulation and data input. CALSIM II includes monthly hydrologic data sets and simulates operations and river flows on the same time step. Average flows over the monthly time step will obscure daily variations that may occur in the rivers due to dynamic system-routing effects or natural hydrologic variability. The monthly time step also requires averaging (usually day-weighted) to simulate operations for regulatory criteria that are specified for a portion of a month. Special procedures have been developed for VAMP-, X2-, and export-based sub-monthly criteria. The averaging process can lead to either under- or over-estimation of water availability or costs associated with the criteria.

The CALSIM II model also uses generalized rules to specify the operations of the CVP and SWP systems. These rules have been developed based on significant CVP/SWP operator input, but still represent coarse estimates of project operations over all hydrologic conditions. The results from a single CALSIM II simulation may not necessarily represent the exact operations for a specific month or year, but should reflect long-term trends. CALSIM II is most appropriately applied as a comparative tool to reflect how changes in facilities and operations may affect the CVP-SWP as has been used in these study. The model should be used with caution to prescribe seasonal or to guide real-time operations, predict flows or water deliveries for any real-time operations.

Additional information is provided through the CALSIM II Peer Review Process which can be found at http://baydeltaoffice.water.ca.gov/modeling/hydrology/CalSimII/index.cfm.

There are also limitations inherent in the use of a one-dimensional model, such as DSM2, to predict hydrodynamics and salt transport in a complicated physical environment like the Sacramento/San Joaquin Delta. A one-dimensional model assumes that a single average velocity, over the channel cross section, can adequately represent velocity in a channel, meaning that variations both across the width of the channel and through the water column are negligible. DSM2 does not have the ability to model short-circuiting of flow through a reach, where a majority of the flow in a cross section is confined to a small portion of the cross section. DSM2 also does not explicitly account for dispersion due to flow accelerating through channel bends.

A.2 SUMMARY OF KEY OBSERVATIONS FROM MODELING RESULTS

Table A-1 presents a summary of key observations from the modeling results. This table presents a synopsis of operation controls, Delta flows, exports, water quality, and particle transport and fate modeling results. In addition, a sampling of modeling results for Below Normal years are provided in Figures A-3 through A-14 to provide the reader with a "feel" for the conditions resulting from each option. Detailed modeling results for each option are presented in Appendices D-G.

Option 1

The most significant change in the "less restrictive" scenario of Option 1 is the removal of the export-inflow ratio control. The removal of this control allows greater exports, but results in lower outflows and increased X2 position under certain conditions. The D-1641 Agricultural standards tend to control more frequently as compared to the Base.

Under the "more restrictive" scenario of Option 1, the Old and Middle River flow restrictions dominate the control of project operations. Significant export curtailments are necessary to achieve these restrictions. Delta outflows, QWEST, and Old and Middle River flows are all increased in this scenario as exports are reduced. Upstream reservoir storage tends to be higher in this scenario due to reduced project reservoir releases under this reduced export capability.

Option 2

The most significant observation from the modeling of Option 2 is that the siphon capacity significantly affects the function of this option. The 4,500 cfs siphon capacity also tends to limit the range of conditions between the "less restrictive" and "more restrictive" scenarios. Export curtailments, as compared to the Base condition, are significant in both scenarios. The reduced exports cause increased QWEST and Delta outflows and pushes X2 more westward.

Water quality, however, is improved in Middle River and at the export facilities due to the more direct path for Sacramento River water to flow to the south Delta. Emmaton and Jersey Point water quality also improves as the Delta outflow is increased. Conversely, the EC in Old River is increased and now more closely resembles that of the San Joaquin River. Residence times in the central Delta are expected to be significantly longer than the Base under this option and very few particles reach the export pumps except for those inserted into Middle River.

Option 3

Option 3 allows significant flexibility in terms of CVP/SWP operations and as such allows export similar or greater than the Base study. Despite preferentially operating the peripheral aqueduct diversion, approximately 20% of the total diversions continue to come from south Delta diversions. The Rio Vista flow requirements are the primary control on operations and also contribute to some of the water solely available for south Delta diversions. The additional requirements for Rio Vista under the "more restrictive" scenario contribute to lower exports as compared to the "less restrictive" scenario. To a lesser extent, the introduction of QWEST and Middle River restrictions control project operations.

Water quality at the export facilities is improved due to a greater proportion of the total exports being derived from the Sacramento River. Water quality at Emmaton and Jersey Point, however, is higher than the Base due to slight reductions in Delta outflow. Particle tracking simulations indicate that the longer residence times are expected in the central Delta under this option. In general, results indicate particle fate similar to Option 2 when the siphon is being operated and similar to Option 4 when the peripheral aqueduct diversion is being operated. However, it should be noted that there are periods of simultaneous operation of both diversion facilities.

Option 4

The modeling of Option 4 was challenging due to the resulting tradeoffs of Rio Vista flow requirements and upstream storage conditions. The addition of the greater flow requirements at Rio Vista caused increased releases from upstream reservoirs. These releases caused Oroville reservoir storage, in particular, to be drawn down further than would likely be permissible during critical periods. The reduction in exports is primarily due to this reduced water supply condition upstream.

As anticipated, water quality at the export facilities is significantly improved and is the same as Sacramento River water quality. EC at Emmaton and Jersey Point is generally reduced as the lack of south Delta diversions reduces intrusion of Bay salt. More complicated, however, is the EC in Old River which is reduced in the fall but increased in winter and spring as San Joaquin River and Bay salt contribute to varying degrees. Longer central Delta residence times are expected under this option and no particles were observed to enter the Isolated Facility. However, due to longer residence times more particles are observed in the modeling to be drawn into the in-Delta Agricultural diversions.

Table A-1. Key Observations from Modeling Results

Scenario	Operations Control	Delta Flows	Exports	Other System Responses	Water Quality	Particle Transport and Fate
1A	• Export-inflow ratio controls removed • DCC change in June from Base • More frequent Ag water quality controls	• SJR flow shift in Apr-May due to different implementation of VAMP • Rio Vista flow increase and QWEST decrease in June due to DCC change	• Increase (~110 TAF/YR) primarily due to exclusion of export-inflow ratio standard	• Upstream storage conditions similar to Base	• Export and Old River (Hwy 4) EC decreased in Dec-Mar due to increase in exports (more Sac water) • Slight increase in Emmaton/Jersey Pt EC due to reduced outflow/QWEST	• Similar to Base conditions
1B	• OMR flow restrictions is primary control • X2 controls in Apr-Jun	• Delta outflow and Rio Vista flow increased due to export reductions and X2 requirements	• Decrease (~3.8 MAF/YR) primarily due to OMR flow requirements	• Upstream storage higher than Base as projects release less water due to limited export capability	• Export/OR (Hwy 4) EC significantly increased in Dec-May due to decrease in exports (less Sac water) • Emmaton/Jersey Pt EC reduced due to higher outflow/QWEST	• Longer central Delta residence times • Greater lag time for particles to reach pumps, but general patterns similar to 1A

Table A-1. Key Observations from Modeling Results (continued)

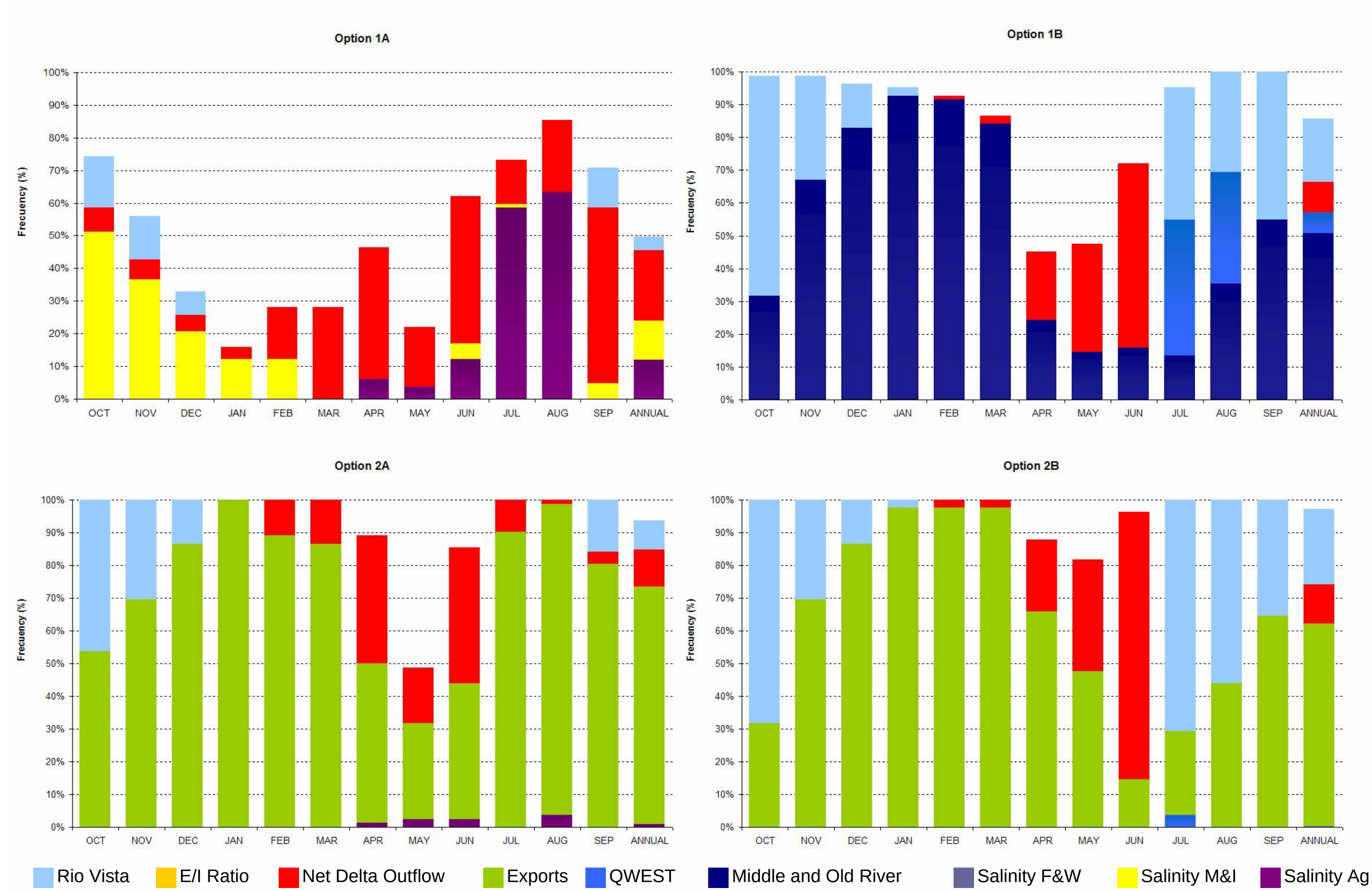
Scenario	Operations Control	Delta Flows	Exports	Other System Responses	Water Quality	Particle Transport and Fate
2A	• Siphon capacity is primary control	• QWEST flow significantly increased • Rio Vista flow increased Feb-Jun (X2), decreased Jul-Sep (balanced conditions) • Delta outflow increased due to lower exports • OMR flows greater than -4,000 cfs	• Decrease (~2.8 MAF/YR) primarily due to siphon capacity	• Upstream storage higher than Base as projects release less water due to limited export capability	• Export EC lower than Base in all months • OR Hwy4 higher than Base in all months, except Oct-Nov due to SJR contribution • Emmaton/Jersey Pt EC reduced due to higher outflow	• Longer central Delta residence times if particles are not in Middle River • Very few particles reach export pumps except those inserted into Middle River • Most particles move past Chipps when released in vicinity of confluence
2B	• Siphon capacity is primary control • Greater X2 and Rio Vista controls	• QWEST positive • Rio Vista flow increased Feb-Jun (X2), decreased Jul-Sep (balanced conditions) • Delta outflow increased due to lower exports • OMR flows greater than -4,000 cfs	• Decrease (~3.4 MAF/YR) primarily due to siphon capacity	• Upstream storage higher than Base as projects release less water due to limited export capability	• Export EC lower than Base in all months • OR Hwy4 higher than Base in all months, except Oct-Nov due to SJR contribution • Emmaton/Jersey Pt EC reduced due to higher outflow	• Longer central Delta residence times if particles are not in Middle River • Very few particles reach export pumps except those inserted into Middle River • Most particles move past Chipps when released in vicinity of confluence • Shorter residence times in central Delta compared to 2A

Table A-1. Key Observations from Modeling Results (continued)

Scenario	Operations Control	Delta Flows	Exports	Other System Responses	Water Quality	Particle Transport and Fate
3A	• SWP/CVP diversion through Isolated Facility and siphon • Rio Vista and X2 dominate controls	• QWEST increased Oct-May, similar to Base Jun-Sep • Rio Vista flow decreased and controlling • Delta outflow reduced Oct-May, similar to Base Jun-Sep • OMR flows generally greater than -4,000 cfs	• Increase (~400 TAF/YR) from Base due to increased flexibility	• Upstream storage conditions similar to Base	• Export EC lower than Base in all months – greater Sac R proportion • OR Hwy4 higher than Base in all months, except Oct-Nov • Emmaton/Jersey Pt EC higher than Base in all months due to reduced Sac R flows to mix with higher bay salt	• Similar to 2A when siphon exports are occurring • Similar to 4 when no south Delta exports – long central Delta
3B	• SWP/CVP diversion through Isolated Facility and siphon • Rio Vista and X2 dominate controls	• QWEST positive • Rio Vista flow decreased and controlling • Delta outflow increased Feb-Jun, similar to Base Jul-Jan • OMR flows generally greater than -3,000 cfs	• Similar to Base	• Upstream storage conditions similar to Base	• Export EC lower than Base in all months – greater Sac R proportion • OR Hwy4 higher than Base in all months, except Oct-Nov • Emmaton/Jersey Pt EC higher than Base in all months due to reduced Sac R flows to mix with higher bay salt	• Similar to 2A when siphon exports are occurring • Similar to 4 when no south Delta exports – long central Delta • Shorter central Delta residence times compared to 3A

Table A-1. Key Observations from Modeling Results (continued)

Scenario	Operations Control	Delta Flows	Exports	Other System Responses	Water Quality	Particle Transport and Fate
4A	• SWP/CVP diversion through Isolated Facility only • Rio Vista and Delta water quality <u>dominate</u> controls	• QWEST positive • Rio Vista flow decreased and controlling • Delta outflow reduced Feb-Jun • OMR flows generally greater than -1,000 cfs	• Slight decrease (~70 TAF/YR) from Base due to lower storage conditions	• Upstream storage was lower than Base due to Rio Vista minimum flow requirements • Upstream vs downstream tradeoff significant	• Export EC lower than Base in all months – Sac R water quality • OR Hwy4 lower in fall, but increased in winter-spring • Emmaton/Jersey Pt EC reduced due to less ocean salt intrusion with no south Delta diversion	• Longer central Delta residence times • No particles drawn into exports • Due to longer residence times, more particles taken by Ag intakes
4B	• SWP/CVP diversion through Isolated Facility only • Rio Vista minimum flow requirements and X2 <u>dominate</u> controls	• QWEST positive • Rio Vista flow decreased and controlling • Delta outflow increased by ~ 1.2 MAF/YR due to X2/Rio Vista requirements • OMR flows generally greater than -1,000 cfs	• Decrease (~770 TAF/YR) from Base due to lower storage conditions	• Upstream storage was lower than Base due to Rio Vista minimum flow requirements • Upstream vs downstream tradeoff significant	• Export EC lower than Base in all months – Sac R water quality • OR Hwy4 lower in fall, but increased in winter-spring • Emmaton/Jersey Pt EC reduced due to less ocean salt intrusion with no south Delta diversion	• Similar to 4A



0

Figure A-2a. Simulated Delta operational controls in Option 1 and Option 2

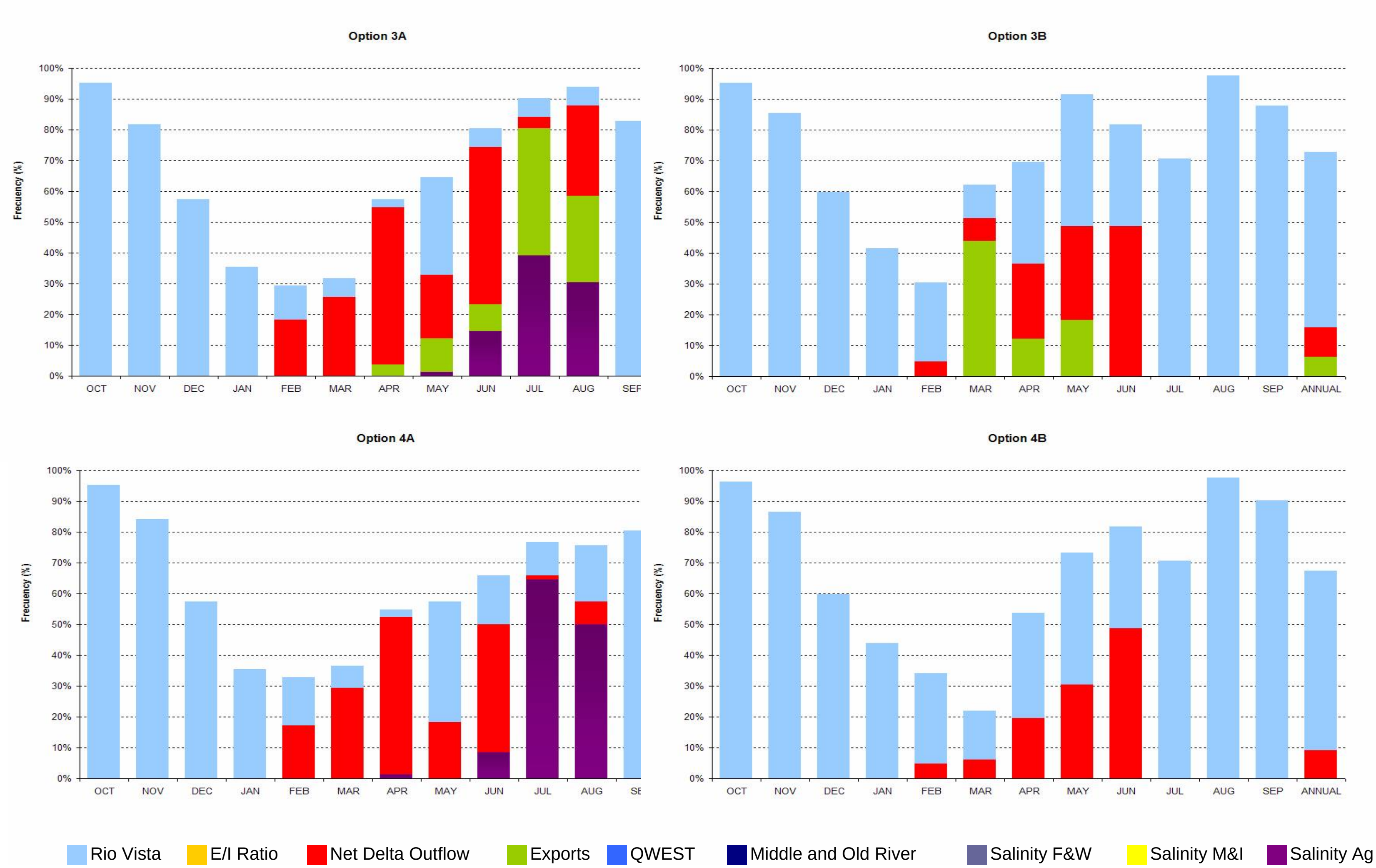


Figure A-1b. Simulated Delta operational controls in Option 3 and Option 4

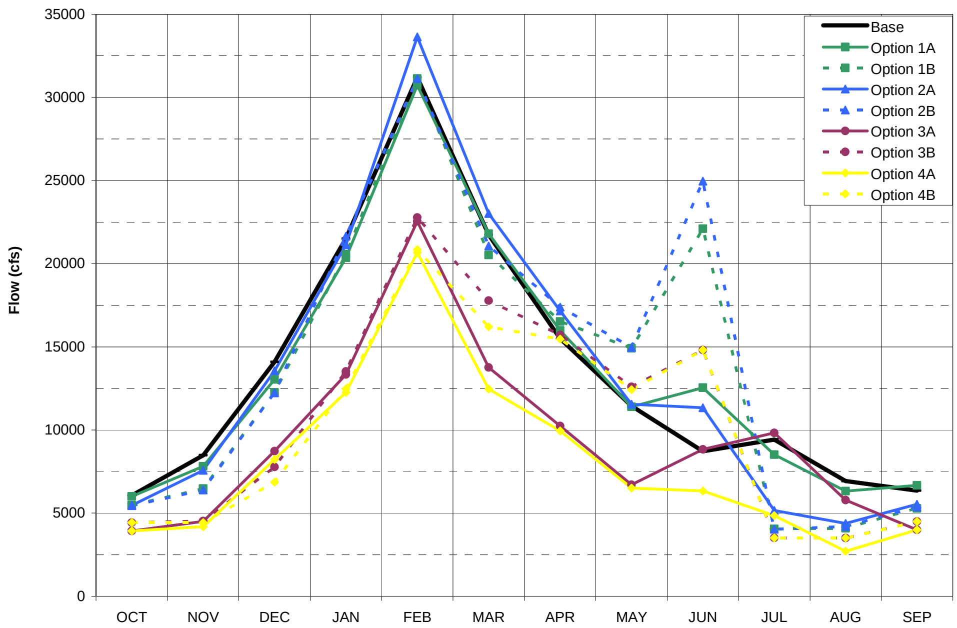


Figure A-2. Sacramento River at Rio Vista monthly average flow for below normal years

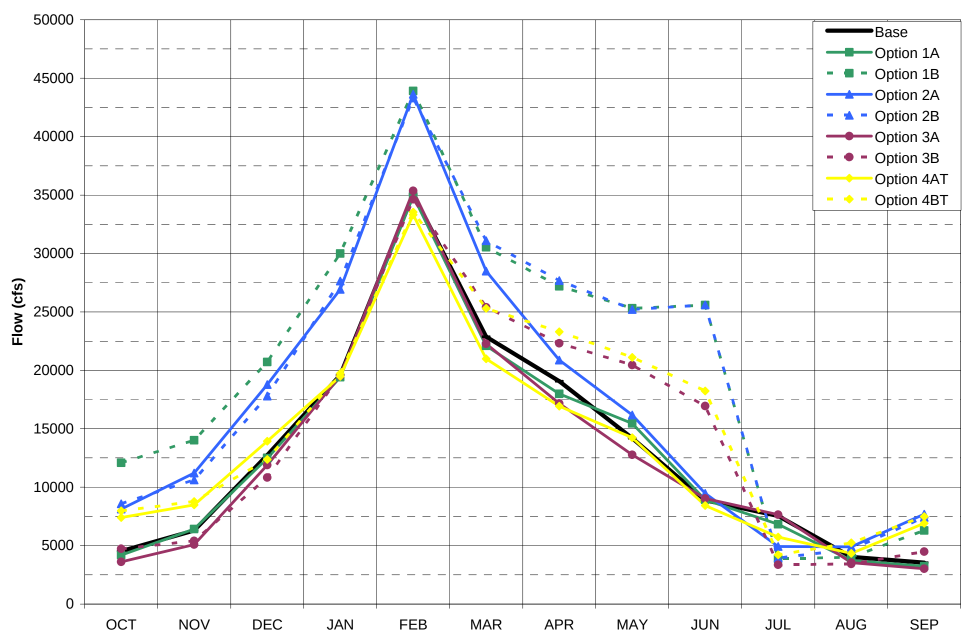


Figure A-3. Delta outflow monthly average flow for below normal years

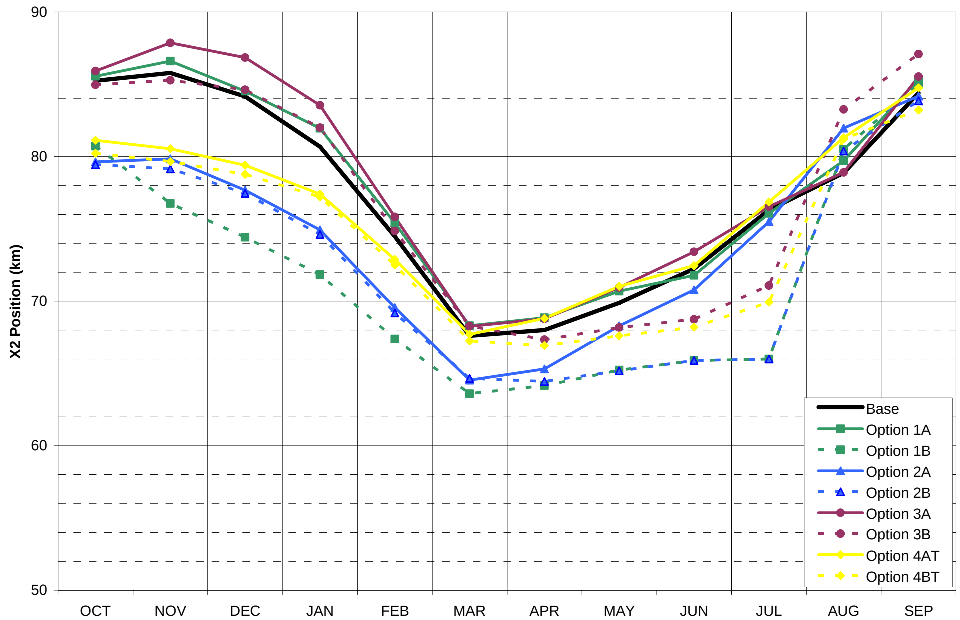


Figure A-4. Monthly average X2 position for below normal years

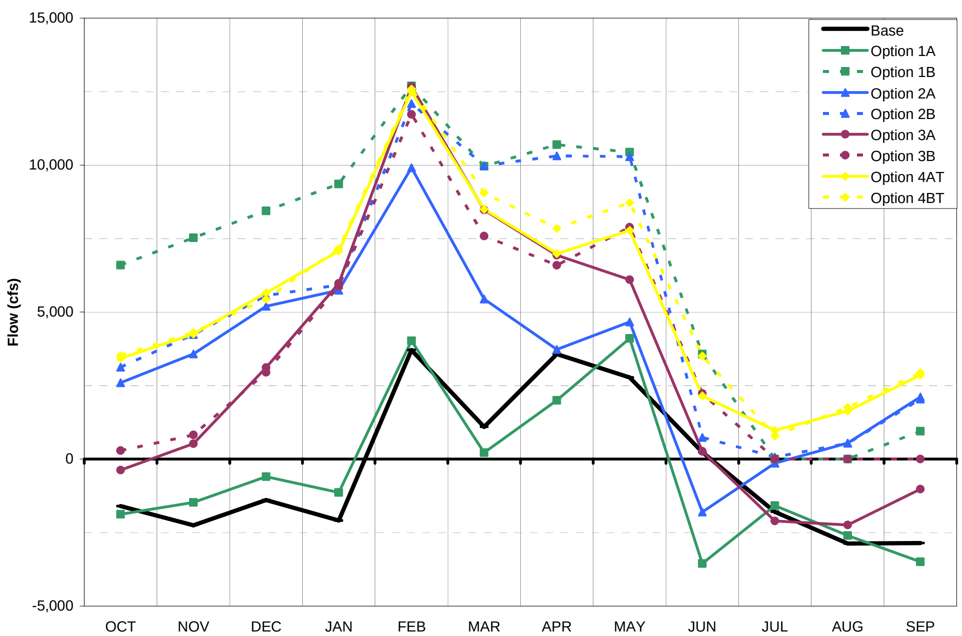


Figure A-5. QWEST monthly average flow for below normal years

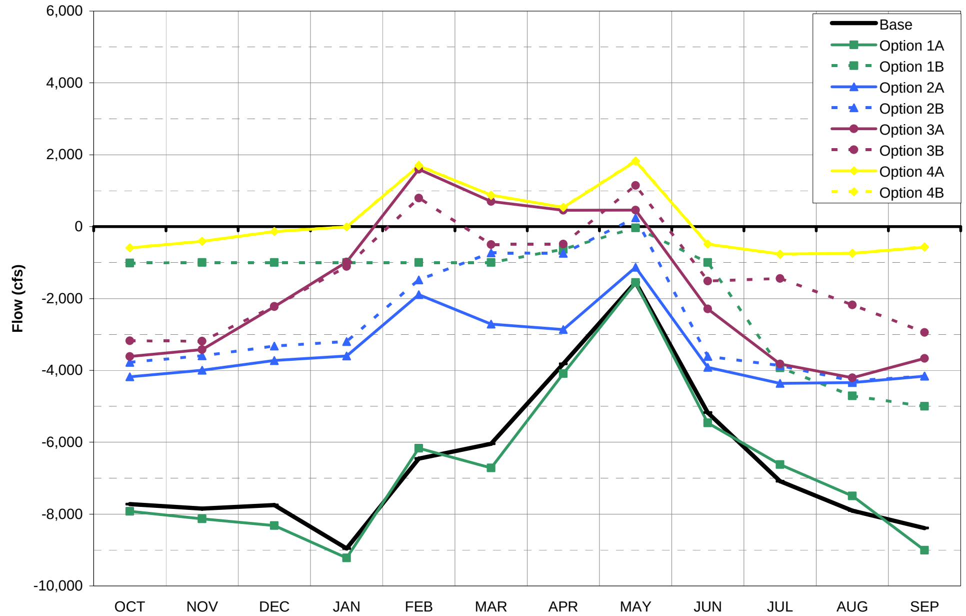


Figure A-6. Combined Old and Middle River monthly average flow for below normal years

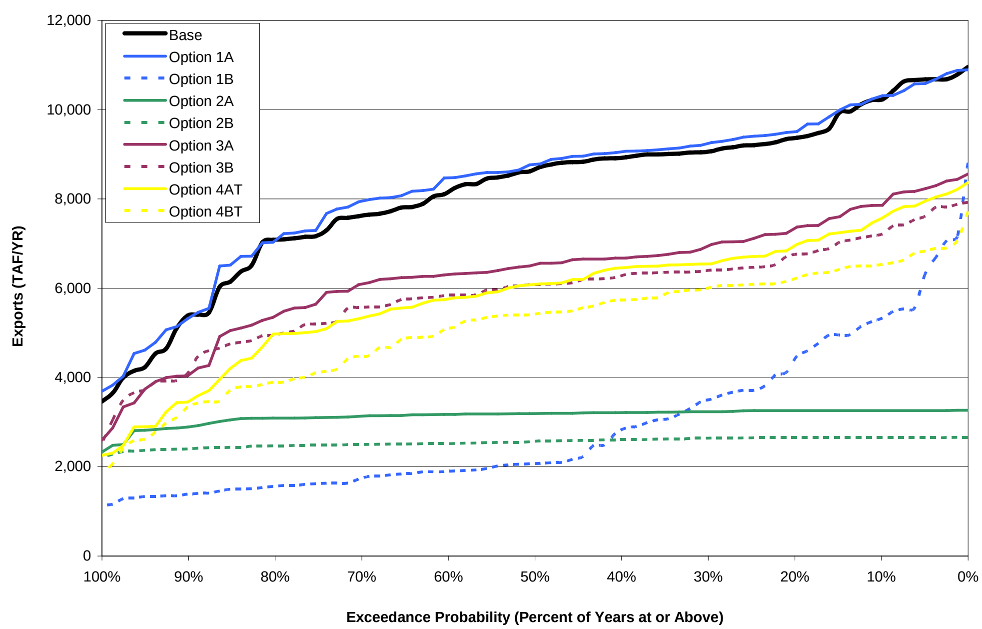


Figure A-7. CVP/SWP annual export reliability

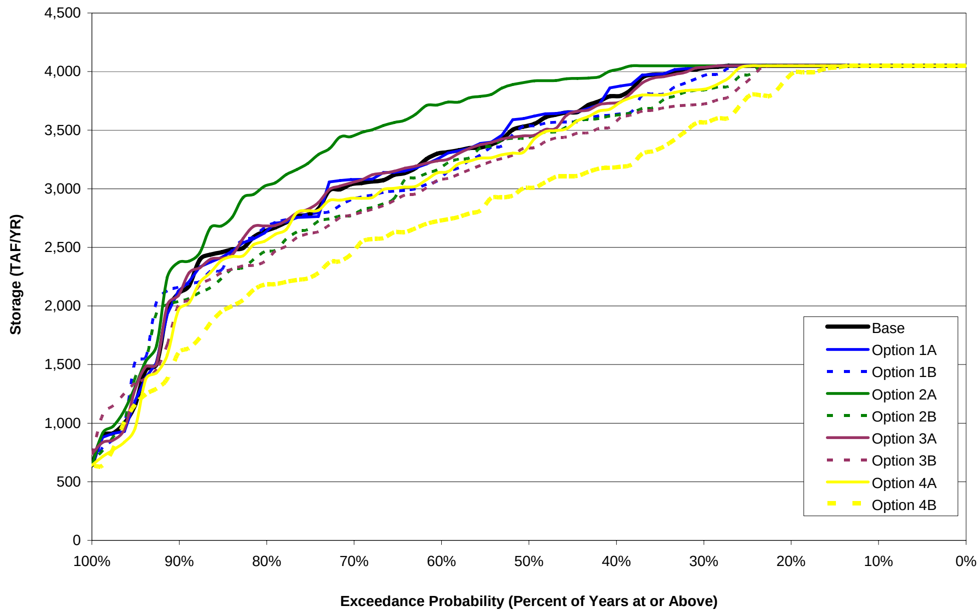


Figure A-8. CVP north of Delta end of September storage (Shasta plus Folsom) exceedance probability

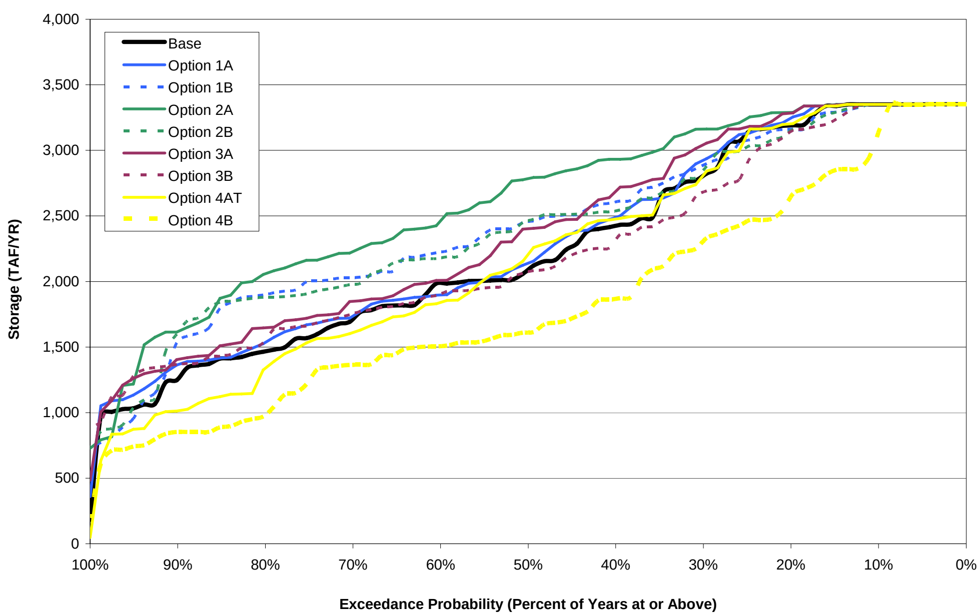
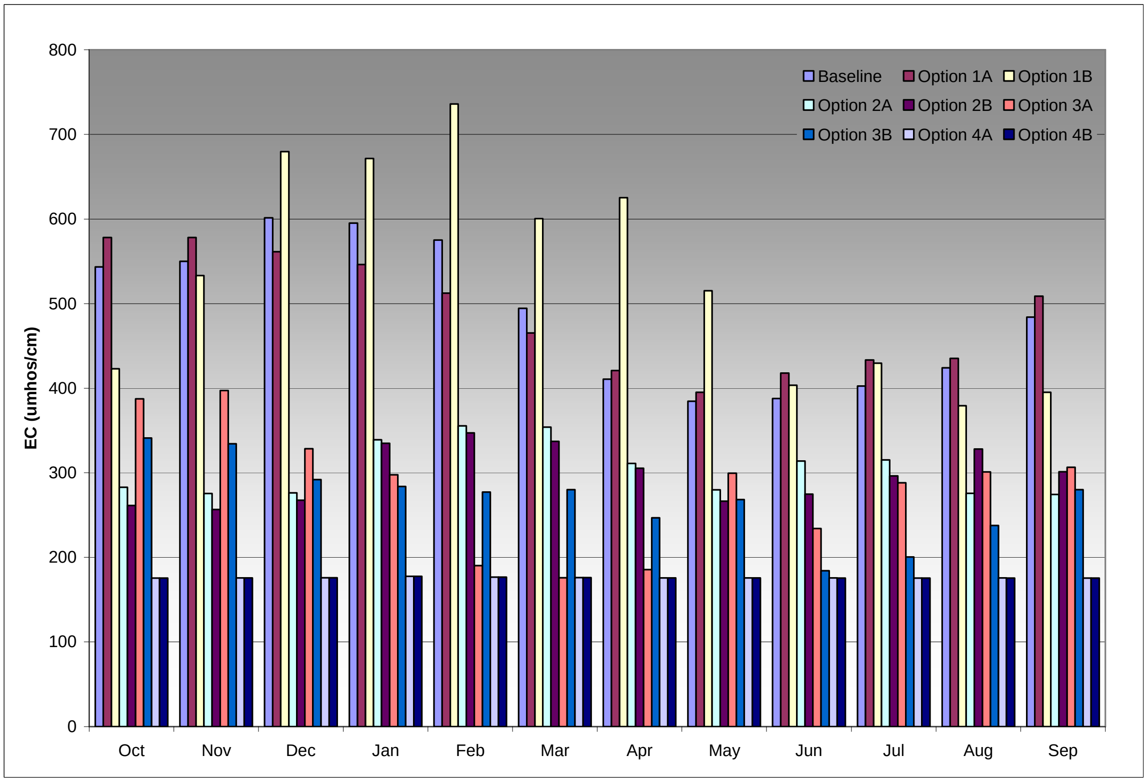


Figure A-9. SWP north of Delta end of September storage (Oroville) exceedance probability



Note: EC for Baseline, Option 1A and Option 1B is blended between Banks and Tracy. EC for Option 3A and Option 3B is blended between IF and Siphon

Figure A-10. Average export water quality, 1975-1991

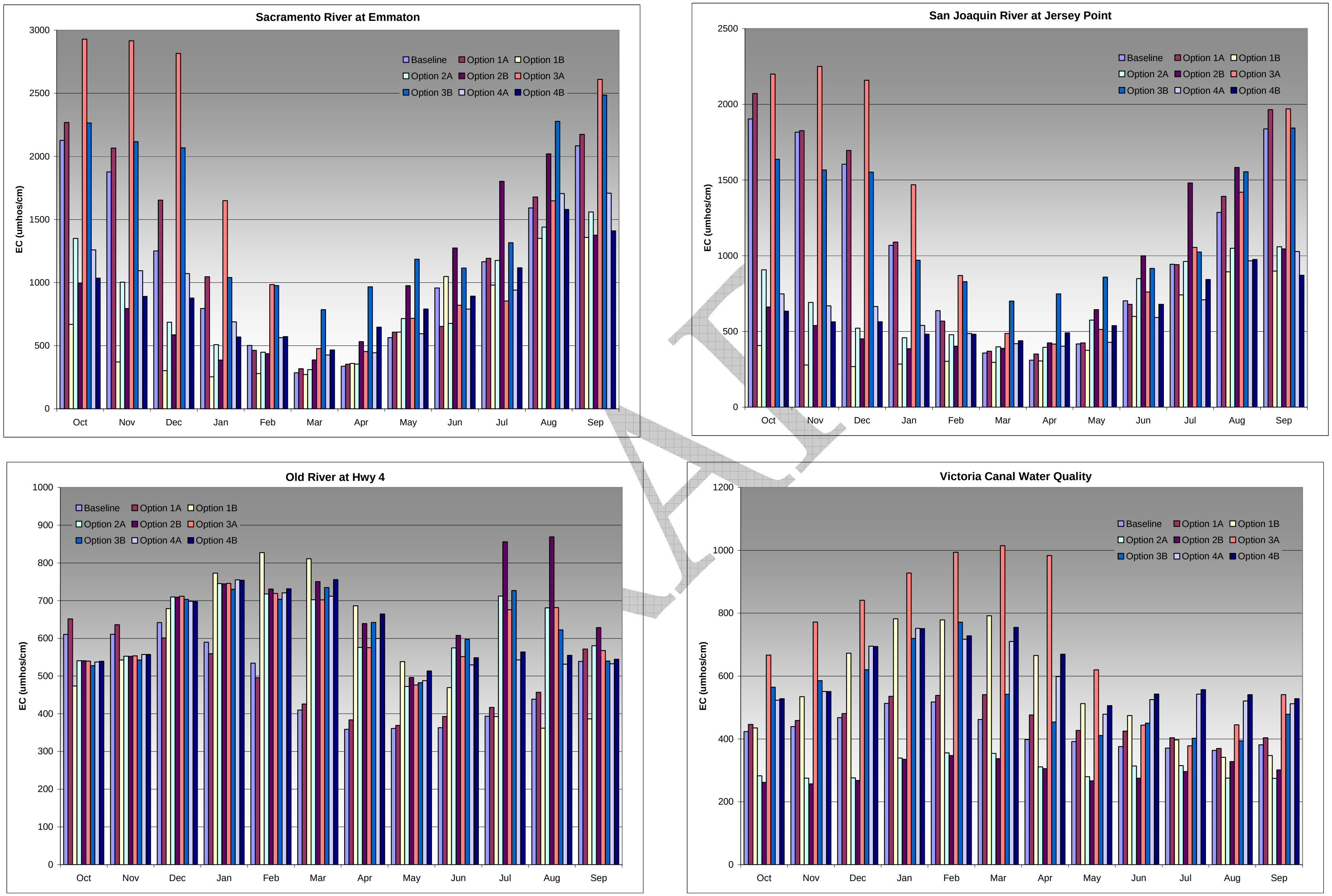


Figure A-11. In Delta average water quality, 1975-1991

This page intentionally left blank.